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Railroad Water Tanks

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# RAILROAD WATER TANKS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Harry Ashton Roberts

ENTITLED Railway Water Tanks

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

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HEAD OF DEPARTMENT OF Civil Engineering.

# An Investigation of Railroad Water Tanks.

Water tanks are fundamental for the operation of a railroad. There ought to be a tank for every 15 or 20 miles of track, so that no greater amount of water need be hauled over the road than is absolutely necessary. When we consider that these tanks cost from $1,200 to $3,000 each, and that the maintenance may amount to $25 to $50 annually, we see the importance of this subject. Realizing this and desiring a more intelligent understanding of this branch of railroad maintenance, the author has made a study of plans and specifications employed by different roads, and also consulted a number of men in supervision of this service. An attempt has been

made to present, in this paper, some of the more important facts which have been collected, together with certain theories which are useful in designing tanks.

The subject will be presented in the following order:

I. Location and Height of Tank.

II. Wooden Tanks.

a. The Tank.

b. The Tower.

III. Steel Tanks.

a. Steel Stand Pipes.

b. Elevated Steel Tanks.

## Location and Height of Tank.

The location and height of tank are to a great extent dependent upon each other; and the peculiar conditions at each water station may determine one or the other of these, and consequently no general rule can be given for the most economic arrangement.

The usual custom is to place the tank close to the track, although a few companies have adopted the plan of removing the tank to the edge of the right of way, using water-cranes from which to take water. There are many good features in the latter practice: the space along the track is generally valuable; the tank may have to give space at any time for sidings or buildings; danger of accident is materially removed; leakage from tank often flows over the rails, and freezing during cold weather

may cause a derailment; and because of seepage, it is difficult and expensive to maintain the road-bed near the tank. On the other hand, removing the tank to a distance causes constant expense for pumping, because this distance is a determining factor in the necessary height of tank. For every 100 feet of 12-inch pipe with water flowing through at the rate of 3,000 gallons per minute, there is a loss of head of 2.56 feet due to friction; and hence a tank situated 100 feet distant from the point where water is taken, must be 2.56 feet higher than a similar tank at that point. There are additional losses of head due to friction in valves and bends which are greater in the first case than in the second.

The tank should be located at the point where water is taken instead of at

the pumping station, when the latter is some distance from the former. There are 10 hours in which to pump 100,000 gallons of water to the tank, but only 2 minutes in which to fill the engine from the tank. Since the friction varies directly as the square, approximately, of the velocity and inversely as the diameter of the pipe, it is evident that a small pipe may be used between the pump and the tank, but a large one is necessary between the tank and the spout. Therefore it is better to use a long line of small pipe from pump to the tank than to use a long line of large pipe from the tank to the tender.

For wooden substructures the height varies from 15 to 30 feet from base of rail to bottom of tank. When a greater height is needed, steel is generally used in the substructure;

but a height greater than 50 feet is seldom required.

## Wooden Tanks.

The Tank. Wooden tanks were formerly made of the best, clear, soft, white pine; but because of the growing scarcity of that material, Louisiana and red swamp cypress, Oregon fir, Oregon cedar, common eastern white cedar, California redwood, and a poorer grade of soft pine, known as "tank lumber," have been substituted with considerable success. The recommendations of the committee of Railway Supt. Association of B. and B. is that the material be "first class white pine" though some authorities claim that a number of the above named timbers will outlast the pine.

The size of tank most commonly in

use is 16 feet high by 24 feet in diameter with a capacity of approximately 50,000 gallons. Specifications for the timber in such tanks are as follows: "All pieces shall be full length without splicing and be made from 3-inch first selected, soft, white pine plank, free from coarse or loose knots, sap, shakes or any imperfections that can cause a leak. All joints shall be machine sawed with a fine 90 per cent scarf mark, and shall have dowel pins at 4-foot intervals. The outside of the staves shall be surfaced convex to conform to the circle of the tank. No stave shall be more than 8 inches wide and no bottom plank more than 12 inches wide. The crozing at the chime shall be cut 3/4-inches deep and with due allowance for the pitch of the staves. All black heart knots, not extending clear through the plank,

shall be bored and carefully plugged with white pine. All planks for the staves and the bottom must exclude the heart. No sap shall be allowed on the inner edge; and on the outer edge not extending inwardly more than ½ inch and not more than ¾ inches across the plank." *

The hoops are made of wrought iron and vary in number, for a 16 × 24-foot tank, from 12 to 15. They are usually about 6" × 5/16" at the bottom and decrease to the top where they are usually about 1½" × 1/8". In some cases the size diminishes regularly from the bottom up; while in others, only one or two sizes are used. The hoops fail most often by corrosion on the inside surface, due either to moisture coming through the staves or because the non-convexity of the

* Mr. P. W. Snow, in Journal, Western Soc. Engr., June, 1899.

surface of the staves allow moisture to get in from the outside. Before placing the hoops on the tank, they should be painted on the inner surface. Some tank makers galvanize the hoops at a small additional expense. Generally the wood of the tank will out-last two or three sets of hoops.

The method of joining the ends of the hoops is of great importance, as a weakness at this point is a very fruitful cause of failure. This failure is due, (1) to failure in the hoops themselves, (2) weakness in the lug bolts, (3) improper transmission of the pull of the bolts, (4) improper fastening of the lugs to the hoops, and (5) slipping of the friction-grip lugs. One of the best forms of fasteners on the market is made of a pressed steel loop riveted to the hoop and connected by a single draw rod which is adjusted by means of a nut and threads at each

end.

In cold climates a frost-proof roof and also an air space in the bottom of the tank should be used, as they tend to prevent freezing.

The life of the ordinary wooden tank averages about 20 years, though it is not uncommon to hear of one which has been used 30 years or longer. If a tank could be kept constantly full of water, and if those parts exposed to the air could be kept well painted and free from moisture, its life would be prolonged indefinitely; but these are ideal conditions which can not be attained. A tank should not be allowed to stand empty for any length of time and the exterior should be kept well painted. It is unnecessary to paint the interior except near the top. The tank begins to rot near the top edges

of the staves because at this point the timber is exposed alternately to air and water. If the interior of the tank were painted from 5 to 8 feet down from the top, it would tend to increase its life.

The Tower. With wooden substructures, as before noted, the usual height is from 15 to 30 feet. The lumber for this tower is ordinarily of pine, but oak and other timbers are sometimes used. Some roads make a practice of using old bridge timbers for this purpose; but this is bad practice and they had better be left in the bridge. In either case there is liability of an accident. Then too, old timbers will hardly last long enough to pay for the labor of working them up, exceptional cases to the contrary.

The usual method of arranging the timbers for the tower is shown in Fig. 1.

The timbers are 12"x12" and are braced with iron tie-rods and wooden struts. The four center posts may be used as studding upon which to attach a shelter for the inlet pipe. Wooden sills should

Fig. 1.
PLAN FOR FOUNDATION.

never be used between the stone caps and the posts, because they will rot out in a short time being in a position to catch and retain all moisture. Cast-iron corbels or bearing plates should be used instead.

Some years ago cast-iron columns were substituted for wooden ones by some roads, but it is not practical to use cast-iron posts more than about 20 feet high.

Steel substructures will undoubtedly replace both wood and iron in the near

future. For towers of a greater height than 30 feet, steel should in most cases be used. Of course in a wooded country, the cheapness of wood will retain it in favor for many years. Some companies work up old rails for this purpose, but this has proven to be almost as expensive as to use new material. The same general arrangement of posts is used with steel substructures as with wood and cast-iron.

The foundation usually consists of a pier for each post, though in some cases the practice is to make a monolithic foundation of concrete. The material used for the piers depends upon locality and the practice of the company. Concrete is coming to be used quite generally. It is cheaper than stone, more easily handled, and requires less skilled labor to construct. Only the best

Portland cement should be used in proportions as follows: 1 volume of Portland cement, 3 volumes of sand, and 6 volumes of broken stone. Stone piers are stepped, but with concrete they are more easily made trapezoidal in vertical cross section.

The area of the bottom of the piers depends upon the size of the tank and the bearing power of the soil. An ordinary 16×24-foot white pine tank with frost-proof roof and steel substructure 20 feet in height, weighs when full of water about 225 tons. Supposing the piers to take an equal part of this weight, each will carry 18.8 tons to the soil. As well drained clay will bear from 2 to 4 tons per sq. ft., a base 3 to 4 feet square will be sufficient. Table I, taken from Baker's Masonry Construction gives the bearing power of different soils.

The pier should be deep enough that it will not be injured by the upheaving

Table I.

Safe Bearing Power of Soils.

| Kind of Material. | Safe Bearing Power. Tons per sq. ft. Min. | Max. |
|---|---|---|
| Rock - the hardest - in thick layers in native bed | 200 | — |
| " equal to best ashlar masonry | 25 | 30 |
| " " " " brick " | 15 | 20 |
| " " " poor " " | 5 | 10 |
| Clay in thick beds always dry | 4 | 6 |
| " " " " moderately dry | 2 | 4 |
| " soft | 1 | 2 |
| Gravel and coarse sand, well cemented | 8 | 10 |
| Sand, compact and well cemented | 4 | 6 |
| " clean, dry | 2 | 4 |
| Quicksand, alluvial soils, etc. | 0.5 | 1 |

effect of the frost, which of course, varies with the latitude of the place.

Piles have been and are yet used to some extent for these foundations, but

not by roads whose standards are high.

## Steel Tanks.

For some time it has been recognized that a substitute must be found for the wood of tanks and towers. There are at least three reasons for this: first, timber suitable for tanks and towers is becoming quite scarce and inaccessible and increasing in price; second, wooden tanks have a comparatively short life; third, wooden tanks are limited as to size.

The life of a wooden tank, made from the best material, is about 20 years, cases to the contrary notwithstanding. Then too, this average is taken from the life of tanks made 20, 30, and 40 years ago, when timber was more plentiful and of better quality than now; and consequently this average is too

high for tanks now being constructed. The life of the tank itself is usually greater than that of the substructure, and repairs on both are frequent.

The increase in traffic has necessitated the use of more and larger engines, which in turn calls for a greater capacity of water tanks. Arising from this necessity, a movement was started some years ago and became quite general in 1898 or 1899, among the larger railroad companies to use steel tanks. This movement had hardly gotten well under way, when the sudden rise in price of steel retarded it. But it began again recently with the easing of the steel market, and the promise now is that steel tanks are likely to become standard on the leading roads of the country within a very few years.

Two forms of steel tanks are employed: steel stand pipes, and steel tanks elevated on steel substructures.

Steel Stand Pipes: Of these two forms of steel tanks, the stand pipe seems to be most in favor, having been made the standard for capacities above 50,000 gallons on several important roads.

In designing such a tank, it is necessary first, to determine the thickness of plates required to withstand the water-pressure. Strictly the stresses due to wind and the weight of the metal itself act at right angles to the stresses due to water-pressure and are small in comparison; and hence may be neglected, except in the case of the top plate, which will be considered further on. To determine the thickness of the plate at any point, let

$t$ = thickness in inches,

$h$ = distance in feet of the point below top of tank,

$d$ = diameter of tank in feet,

$s$ = allowable stress in lbs. per sq. in.

and $e$ = efficiency of vertical riveted joints.

The tension to produce longitudinal rupture for a vertical pipe of height $h = 62.5 \times h \times h \times d$. The resistance in the metal which must equilibrate this stress $= 12 \times 2t \times s \times h \times e$. Equating the tension and the resistance gives:

$$24tshe = 62.5h^2d$$

$$\text{or } t = \frac{2.6hd}{se}, \qquad (1).$$

By use of this formula the thickness of the plates necessary at different heights may be determined.

When the water is low, a high wind blowing over the top of the tank tends to create a vacuum in the pipe and causes

large stresses in the top plate. For this reason the top plate must not be less than 1/4 inch thick, and should be reinforced by an angle at the upper edge.

Before designing the foundation, the weight of the tank full of water must be computed. The allowable stress on the masonry may be taken at 5 to 10 tons per sq. ft. The base of the foundation should be large enough to transmit an allowable pressure to the soil. Reference to Table I, page 15 will give the allowable pressure for different soils.

The foundation must also be wide enough to resist the overturning moment due to the wind. The force due to wind may be taken as acting at one half the height of tank, and the amount as equal to a pressure of 40 to 50 lbs. per sq. ft. on one half the vertical projection of the tank. The moment

due to the weight of the tank full of water would, except in cases of very high tanks with comparatively small diameter, overcome the moment due to wind; but in case the tank is empty, anchorage would in general be necessary to prevent overturning. In order to determine the number of anchor bolts necessary, the wind moment is computed and the moment due to weight of the empty tank deducted from it. Let the resulting moment = M. Let I = moment of inertia of n bolts of area, a, about a circle of diameter, d. Then according to Prof. A. N. Talbot,

$$I = \frac{nd^2a}{8}, \qquad (2).$$

If s = the allowable unit stress in bolts, we have the well known formula,

$$M = \frac{sI}{c}, \qquad (3).$$

Substituting for s, $\frac{T}{a}$, in which T = tension in one bolt, and also the value of I from (2) equation (3) becomes,

$$M = \frac{\frac{T}{a} \times \frac{nd^2a}{8}}{\frac{d}{2}} = \frac{ndT}{4}, \qquad (4).$$

from which the number of bolts necessary may be determined.

There should in no case be less than 8 bolts in order that sufficient anchorage may be had. These bolts should be of the best Norway iron; and if welded should be upset. They should be so arranged as to come up as closely as practical to the sides of the tank so that they may not be bent in fastening them to the lugs. Several failures have been caused by this defect, because the vibration of the tank eventually straightens the bolts and causes play on the foundation. The anchor bolts should be secured to anchor plates, so designed that the pressure on the stone work above will not exceed that allowable on such masonry. The bed plates should be heavy enough to carry

the stress to the anchor bolts without flexure.

It is not deemed necessary to have masonry foundations for tanks of a capacity less than 150,000 gallons. Such tanks are set upon a foundation of cinders, gravel, or broken stone without anchorage. In this case the risk is taken that the tank will never be caught empty by a high wind.

For three standard steel stand pipes, 24 feet in diameter and 29, 43, and 60 feet in height, which are in use on one of the largest railroad systems in the country, the weights and capacities above the spout are, respectively, 34,350, 53,760 and 81,850 pounds of steel; and 57,680, 105,580, and 163,840 gallons of water. The foundation for these tanks consists of broken stone.

Elevated Steel Tanks. Where it is necessary to have a great head, as in the case of a tank situated at a considerable distance from the point where water is taken, an elevated tank is more economical than a stand-pipe, because in the stand-pipe there is a considerable part of the water and the tank which act merely as a support for that above. The expense of constructing the lower part of the tank is much more than that of an equal height of trestle: Then too, the foundation must be larger and more expensive for a stand-pipe than for a tower.

The tower for an elevated tank is composed of trestle having four, six or eight posts, made of built-up sections and lateral bracing. For tanks 20 feet high or less, the tower may consist only of columns with small tie-rods between; but above that

height, the construction becomes more complicated. The stresses due to loading are easily computed but the wind stresses enter in as a large factor and one difficult to determine accurately. Professor Marston suggests the following: "The amount of wind pressure may be assumed the same as for stand pipes. On the tower a pressure of 50 lbs. per sq. ft. of all exposed area may be assumed. as regards wind stresses the tower may be considered as a vertical cantilever beam anchored to the ground. Then if we pass a horizontal section at the top of each story, cutting the posts only (between points of attachment of the diagonal bracing), we can get the vertical components of the post-stresses as in a beam made up of parts. Thus let Fig. 2 represent such a section; and let A = section of each post, and r = radius

of tower. The maximum stress in post a will occur when the wind is blowing in the direction aa. If $M$ = the wind moment about the horizontal

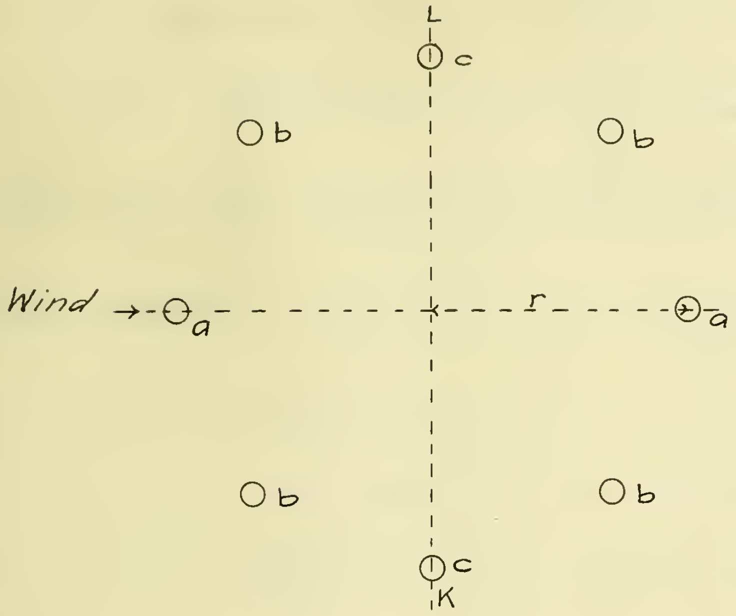


Fig. 2.

plane assumed, the fibre stress in post a will be $f = \frac{Mr}{I}$, where $I$ = moment of inertia of the entire tower above $LK = 4Ar^2$, if we neglect the moment of inertia of each column about its own axis. Hence $f = \frac{M}{4Ar}$; and therefore the total column stress $= P = fA = \frac{M}{4r}$. The stress in column $b = 0.7\frac{M}{4r}$, and in column $c = 0$. In a six-post tower, $I = 3Ar^2$, and the stress in the remotest post is $\frac{M}{3r}$,

and on each of the others is $\frac{I}{2} \times \frac{M}{3r}$.

"By this method the vertical component for each post acting at the top and bottom of each story can be found. Then taking each story seperately, the stresses in the diagonal rods can be found by equating the vertical components acting at the top and bottom of each post, beginning with post a where the stresses on the two diagonals attached thereto are equal. The actual post-stresses are then found by equating the vertical components at either the top or bottom joint. Finally the stresses in the lateral struts are obtained by use of two equations of the components in a horizontal plane acting at a joint."

In such a tank care must be given to secure good anchorage for each post. The moment arm of the wind is so great that a large uplifting force is generated and the foundation

should be heavy enough to overcome this force, as well as large enough to deliver a safe bearing pressure to the soil. However it is only in special cases that a tank, elevated to a greater height than 50 feet, is used for a railroad water station. In this case the construction of the tower, as before noted, is quite simple, as is also the foundation. The tank itself is made similar to the stand pipe and the formulas used in computing the thickness of the plates are the same in both cases.

Until recently the bottom of the tank was made of flat plates riveted together and set upon a flooring of beams; but at present, the hemispherical, segmental or conical bottom is used to a great extent. Any one of these forms is better than the flat bottom; and much cheaper, because the legs are fastened at the

periphery only, thus saving the expense of a floor system of beams. In designing such a tank, special

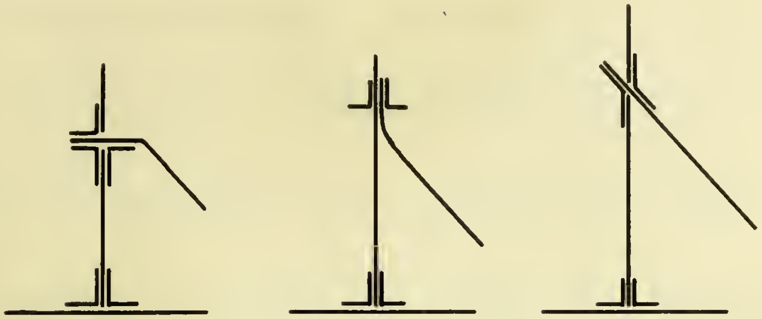


Fig. 3.

care should be used in the manner of joining the bottom and side plates, and also in fastening the legs. Three ways of fastening the bottom and side plates are shown in Fig. 3. The first is a bad form and should never be used. A failure of a tank with such a connection between side and bottom plates has recently occurred. Either of the other two are fairly good and much to be preferred to the first. The cross-section of the column for 3 feet below the point where it joins the side plates should have $1\frac{1}{2}$ times the area of the post required to carry the load,

because of the difficulty of securing a good connection to the sides of the tank and also because of large stresses entering in due to the manner of fastening. The following methods of computing the stresses in spherical and conical bottomed tanks is due to Prof. A. N. Talbot.

## a. Hemispherical and Segmental Bottoms.

Z = Vertical stress per lineal unit of circumference.

X = horizontal force toward or from axis of cylinder.

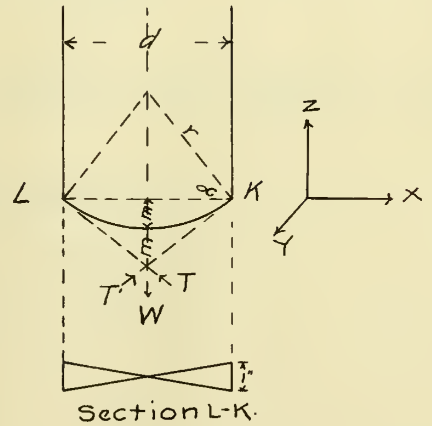


Fig. 4.

Y = circumferential force per lineal unit of the section.

T = tangential force in any direction on the

sphere per lineal unit of distance on a section at right angles to $T$ itself.

Weight of water in tank $= W = \frac{1}{4} \gamma \pi d^2 (h + \frac{1}{2} m)$, (5),

where $\gamma$ is the weight of a cubic unit of water.

$$z = \frac{W}{\pi d} = \frac{\gamma d}{4}(h + \tfrac{1}{2} m), \qquad (6).$$

Suppose a section L-K be cut from bottom of tank as shown, 1 inch long at the circumference. The weight of the water on the area above the section is $2\frac{W}{\pi d}$. This produces a stress in the plates,

$$2T\cos\alpha = \frac{2W}{\pi d}, \qquad (7).$$

From Fig. 4, $\cos\alpha = \dfrac{\frac{1}{2}d}{r}$. (8).

Substituting this value of $\cos\alpha$ in (7) and transposing it becomes,

$$T = \frac{Wr}{\frac{1}{2}\pi d^2} \text{ or } \frac{\gamma r (h + \frac{1}{2} m)}{2} \qquad (9).$$

$$X = T \sin\alpha, \qquad (10).$$

$$Y = \frac{pd}{2\cos\alpha} \qquad (11).$$

in which $p$ is the pressure per sq. in.

## b. Conical Bottoms.

Using the same nomenclature,

$$W = \frac{\gamma d^2 \pi}{4}(h + \tfrac{1}{3}m), \qquad (12).$$

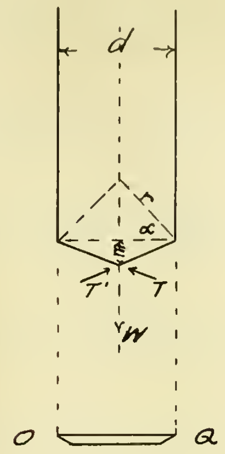


Fig. 5.

$$z = \frac{W}{\pi d} = \frac{\gamma d}{4}(h + \tfrac{1}{3}m), \qquad (13).$$

$$2T\cos\alpha = \frac{2W}{\pi d}$$

$$T = \frac{W}{\pi d \cos\alpha} = \frac{Wr}{\frac{1}{2}\pi d^2} \text{ or } \frac{\gamma r}{2}(h + \tfrac{1}{3}m). \qquad (14).$$

$$X = T\sin\alpha = \frac{W\tan\alpha}{\pi d} \qquad (15).$$

Consider a horizontal section o-a cut from the bottom one inch wide. In case of a cylinder, $pd = 2ts$. Let $T_1' = ts$; then $pd = 2T_1'$.

$pr = T_1'$, where $r = \frac{\frac{1}{2}d}{\cos\alpha}$ from diagram.

Therefore $Y = pr = \frac{pd}{2\cos\alpha}$, (16).

## Summary.

In selecting a standard form of water tank there are two elements that should be considered: first, the tanks should be uniform in size and material over the entire system in order to reduce the first cost and the cost of maintenance; and second, they should be made of some durable material to save trouble and expense in renewals and to reduce the cost of maintenance to a minimum. As has been noted, most roads use tanks of uniform size and material; but in very few cases has the most durable material been selected. The end sought in both uniformity and durability is small expense.

As nearly as can be determined from prices furnished by different roads, the average cost of a 50,000 gallon wooden tank complete,

including material, erection, etc., is \$1,200. A steel stand pipe, with the same capacity above the spout, costs about \$1,800, and an elevated steel tank \$1,400. The shortness of life of wooden tanks, as compared with metal ones, make the former the more expensive in the end. As before stated 20 years is a high average life of wooden tanks. Within that time there will be repairs upon the tank amounting to nearly as much as the difference in first cost between it and the stand pipe.

The life of the metal tank has not been determined. Cases are on record in which such a tank has been in service 35 years and is still in good condition. Moreover the cost of maintenance on such a tank is small. For ordinary stations the elevated tank with hemispherical or segmental bottom is the cheapest and gives much

the best appearance, though it has not yet received much attention from the railroad companies.

Metal has been substituted for wood in railroad water tanks in a few cases and always with entire success; and this substitution must soon take place on many of the best managed systems.